FEB 19 1941

74—2

Proceedings of the American Academy of Arts and Sciences

Vol. 74, No. 2, P. 11-20—October, 1940

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(Continued from page three of cover)

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Presented Nov. 8, 1939. Received Nov. 8, 1939.

Introduction

I have already published[1] measurements of the linear compression of a number of substances up to 12,000 kg/cm^2. Apparatus has now been developed by which this range can be extended to 30,000, and I am now starting a program of measurement of linear compressions in this higher range. There are two necessary preliminaries to such a program. The first is the establishment of the pressure scale by the establishment of pressure fixed points and calibration of secondary pressure gauges. This work has already been done and is being published. The second is the measurement of the absolute compression of some substance of reference; this is the task undertaken in this paper. This task is necessary because the method adopted for the measurement of the linear compression of most substances is a differential method—measurement of the difference of compression between the substance in question and a standard. Measurement by difference is used because it is very much more convenient and rapid, although it would be possible to measure the actual compression of many substances by the same method as that used here for the standard substance. As in the previous work, the standard substance is chosen as pure iron.

Method

The general features of the method are the same as before,[2] namely the change of length of a rod of iron is measured relative to the pressure vessel, and this relative measurement is converted into an absolute measurement by an independent and simultaneous measurement of the distortion of the pressure vessel. The whole experimental set-up is, however, so different from that used before that a fresh description of many of the details is necessary. The pressure apparatus now has to be in a single piece, separate pressure chambers connected by tubing no longer being feasible; this results in a much decreased length of the specimen with corresponding loss of sensitiveness. The length was less by a factor of about 5. However, the chief interest in pushing the results to a higher pressure range is in the departures from linearity. Other things being equal, the accuracy with which the second degree term in the pressure can be determined increases as the square of the range. The range is here increased by a factor of 2.5 ($= \sqrt{6.25}$), thus somewhat overbalancing the unfavorable factor arising from decrease of length.

The method by which the change of length of the iron rod relative to the pressure vessel was measured is practically the same as that used before.[2] A shoulder on one end of the rod is kept pressed by a stiff spring against a shoulder in the pressure vessel. A high resistance wire is pressed against the other end; this resistance wire slides over a contact fixed to the pressure vessel. Potentiometer measurements of the effective resistance of the wire, made on a potentiometer in the way already extensively used and described, give, after suitable reduction, the mechanical motion. The arrangement is shown in Figure 1.

The arrangement by which the change of length of the pressure vessel was determined had to be materially altered from that used before because of the drastic difference in the arrangements. Formerly the pressure vessel was a long geometrically perfect cylinder, and the change of length was measured with an optical magnifying device between points on the outside opposite the ends of the iron rod. But now the pressure vessel was conical in shape, and it was subjected to external pressure by being pushed into a heavy conical collar. The points on the exterior of the pressure vessel opposite the ends of the rod were therefore inaccessible. Even if these points had been accessible, measurement of the change of external length would probably not have been particularly pertinent because the proportions were such that appreciable warping of the cross section may be anticipated. Under the circumstances it seemed that the best that could be done was to determine the change of length of the vessel from two probe holes, drilled approximately parallel to the axis, as shown in Figure 2. These holes were 1/8 inch in diameter, and were situated about 0.5 inch from the axis, giving therefore about 0.25 inch of solid wall between the hole and the inner bore. So close to the center as this, warping would be ex-

pected to be very much less than at the exterior, since near the axis the warping must be of the second degree in the radial distance.

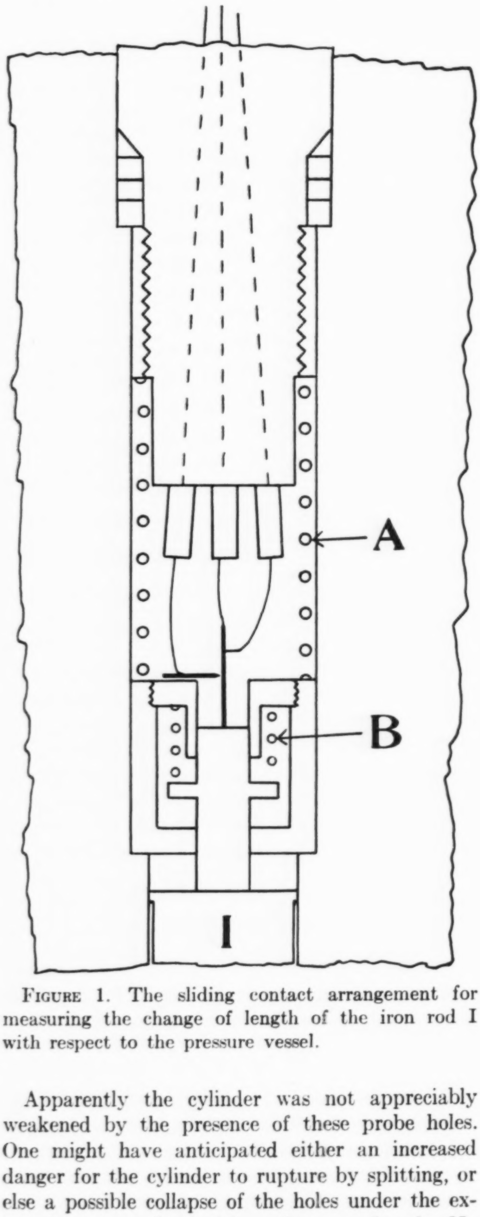

FIGURE 1. The sliding contact arrangement for measuring the change of length of the iron rod I with respect to the pressure vessel.

Apparently the cylinder was not appreciably weakened by the presence of these probe holes. One might have anticipated either an increased danger for the cylinder to rupture by splitting, or else a possible collapse of the holes under the external pressure, but neither effect was found. No permanent change of dimensions of the holes could be detected after use. The probe rods had a clearance for most of their length of 0.010 inch, but where they emerged from the cylinder they were fitted with collars with clearance of only 0.0005 inch in order to reduce play. The lower ends of the probe rods were bevelled at 60°, and the very ends rounded to spheres of small diameter and hardened. A sharply pointed depression in the cylinder to receive them was made with a punch. The relative longitudinal displacement of the probe rods was transferred for measurement to two heavy iron bars, bent as shown in Figure 2, and the relative motion of these bars ultimately determined with an Ames dial gauge, as indicated, graduated to 0.0001 inch. The weight of the bar for the lower probe was entirely taken up by a counterweight with ball bearing pulley, and the bar itself was pressed into firm contact with the probe by a spring, not shown in the figure, thrusting directly in the line of the probe. Contact of the other bar with the upper probe was maintained by the weight of the bar (about 2 kg.), which was not counterbalanced in any way. Three point contact between the two bars was maintained by steel balls rolling in polished V grooves or over polished flats in an obvious enough fashion. The bars were maintained vertical against the tendency of the weight of the upper bar to fall toward the left by a horizontal cord several meters long acting toward the right at the point A.

This elaborate and somewhat clumsy arrangement was made necessary by the exigencies of construction of the press, by the fact that there is a total vertical displacement of the pressure vessel during the run of nearly 0.5 inch as it is forced into its supporting collar, and by the desirability of some sort of arrangement that could be immersed into the temperature bath along with the entire press to permit measurements at higher temperatures. Before this final arrangement was adopted a simpler but less satisfactory scheme of take-off from the probes by a lever arrangement was tried.

The maximum relative displacement of the ends of the probe holes was about 0.00400 inch, in the direction of an extension with increasing pressure. This extension therefore makes the shortening of the iron bar relative to the pressure vessel too large, so that the correction to the relative shortening is subtractive. The longitudinal correction is about one quarter of the measured relative shortening. An error of 0.00001 inch in the longitudinal shortening of the cylinder, which was the limit of sensitiveness of the Ames gauge, corresponds there-

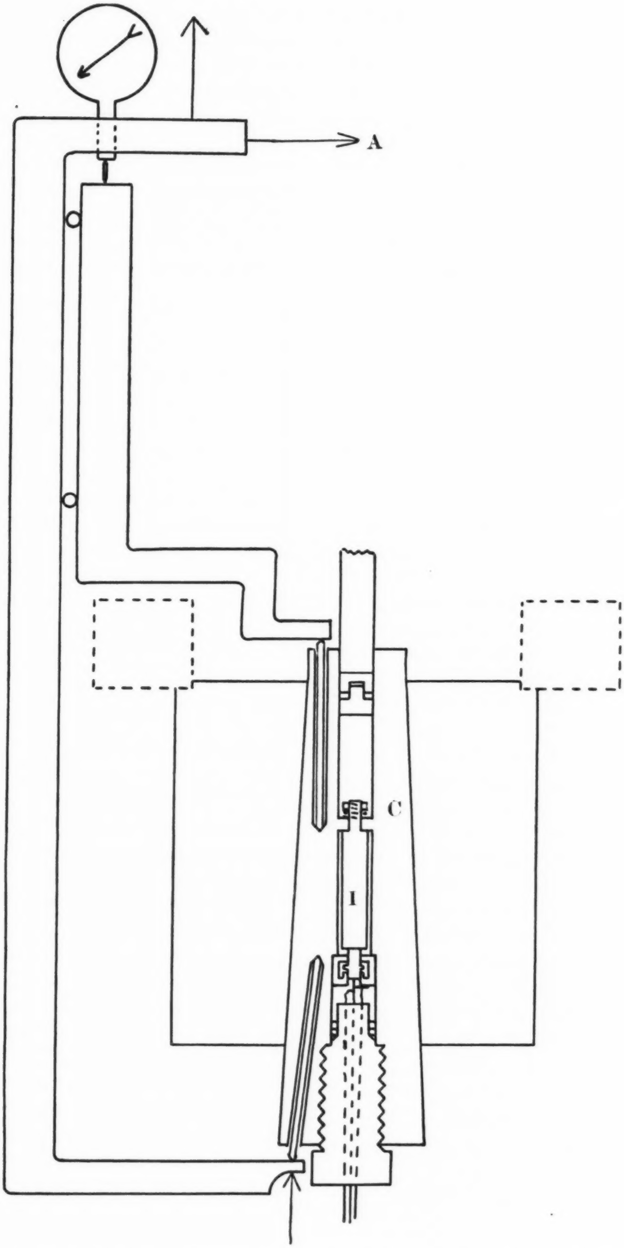

FIGURE 2. General assembly, showing the iron rod I mounted in the pressure vessel C.

fore to an error of 1/1200 in the final result. The sensitiveness of measurement of relative shortening of rod and pressure vessel may be pushed considerably higher by suitably choosing the electrical constants, so that the limiting error, as far as sensitiveness of reading goes, is set by the longitudinal factor.

The measured longitudinal distortion of the vessel is a resultant of several factors, of which the largest are probably internal pressure, external pressure, and longitudinal compression arising from the action of the pressure thrusting the vessel into the external conical collar. These three stresses are not simply related to each other, and the resultant is complex. Since the correction determined by these factors is one third of the final result, and is doubtless the factor limiting the accuracy of the final results, it will pay to discuss it in some detail. By far the largest of the three component effects just mentioned is that due to the external pressure on the vessel due to the thrust into the supporting collar. This effect is naturally an extension with increasing pressure. The effect of internal pressure is on the other hand a shortening. The third component, longitudinal compression due to the thrust, may be shown by simple calculation to be small at the most. Only the roughest qualitative calculation can be made of this, because this compressive thrust is variable along the length of the vessel, having its full value at the bottom, and dropping to zero, in a way not easy to specify exactly, at the top. The two main components in the distortion do not vary in a simple way over the pressure range. With increasing pressure, internal and external components both vary linearly and the resultant total extension is also approximately linear. But with reversal of direction of change of pressure on reaching the maximum, the component due to internal pressure at once starts to reverse itself, whereas external pressure remains constant for a while in virtue of friction in the collar, in spite of the decrease in longitudinal thrust. The result is that the net longitudinal extension continues to increase when pressure starts to drop, reaches its maximum between 20,000 and 25,000, and gives a hysteresis loop of the general form indicated in Figure 3. The amount of external friction and therefore the external pressure can be determined with fair accuracy from the measurements, which were always recorded, of the longitudinal displacement of the pressure vessel into the supporting collar. Given the external and internal pressure it is then possible to reproduce, with an error of perhaps 5 per cent, the longitudinal distortion by a linear expression in these two pressures.

A check can be obtained on the measurements of longitudinal distortion by measuring the relative motion of rod and vessel when external pressure only is applied. In this case there is no change of dimensions of the rod, so that the potentiometer measurements should agree exactly with the distortion measurements. Of course this could be done only over a comparatively small external pressure range, because the maximum external

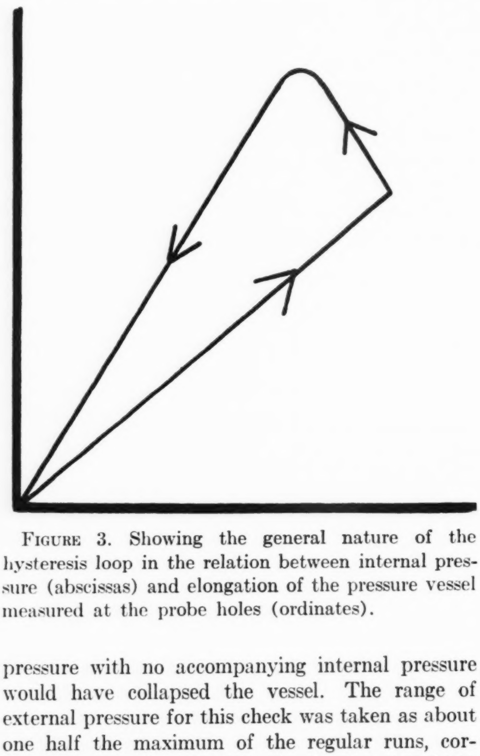

FIGURE 3. Showing the general nature of the hysteresis loop in the relation between internal pressure (abscissas) and elongation of the pressure vessel measured at the probe holes (ordinates).

pressure with no accompanying internal pressure would have collapsed the vessel. The range of external pressure for this check was taken as about one half the maximum of the regular runs, corresponding to about 6,000 kg/cm^2 external (12,000 during regular run). The uncorrected results of the check made in this way were not good; the relation was not linear, there was hysteresis, and different set-ups gave different results. The extension measured by the potentiometer varied on three set-ups from 6 to 17 per cent greater than that measured at the probe holes. The irregularities are probably due at least in part to irregularities in the external friction. There are two conceivable reasons for the discrepancy, granting that the measurements themselves are correct. The

first of these is warping of originally plane sections of the vessel, different in amount at the two ends. Under the conditions of these check measurements it is difficult to estimate even what the sign of this would be, but it would seem that its magnitude must be small. The second and the more important possibility is concerned with the fact that the lower probe hole is not parallel to the axis, but is inclined to it at an angle of 8.15°. This is a bad feature of the design that was recognized in the beginning, but the geometrical restrictions imposed by the rest of the apparatus made it almost impossible to avoid. If the angle 8.15° changes during the extension there is a resolved component along the axis which contributes to the measured longitudinal displacement. It is not difficult to get an approximate numerical value for the magnitude of this effect. In the first place there is the formula of elasticity theory for the ratio of the radial displacement at the radial distance r_a to that at the interior wall r_i in an infinitely long cylinder under external pressure only:

$$\frac{u_{r_a}}{u_{r_i}} = \frac{r_a}{r_i} \frac{\frac{1}{\lambda + \mu} + \frac{r_i}{r_a}\frac{1}{\mu}}{\frac{1}{\lambda + \mu} + \frac{1}{\mu}}$$

The external radius does not enter this expression. Taking $r_a = 1.20$, and $r_i = 0.57$, and for the elastic constants $\lambda = 9.4 \times 10^{11}$ and $\mu = 7.7 \times 10^{11}$, this gives $u_{ra}/u_{ri} = 1.35$. Now u_{ri} is accessible to direct measurement; this was done with a simply constructed bore measurer under the same conditions of external pressure. It should also be possible to calculate u_{ri} directly from elasticity theory, assuming an infinitely long cylinder. The value calculated in this way is 15 per cent less than that directly measured, giving a good enough check considering the crudity of the approximation. u_{ri} now being known, u_{ra} can be at once calculated. To the u_{ra} found in this way a small term amounting to 11 per cent is to be added for the radial expansion of the bottom of the cylinder under the thrust which generates the external pressure. The resolved component of this along the axis can now be obtained, with the result that the longitudinal extension of the vessel measured with the probes corrects up to a value only 1 per cent less than that measured with the potentiometer directly on the inside, giving essentially a check, considering the irregularities. The outstanding discrepancy of 1.0 per cent might be argued to be due to warping of the cross section. This discrepancy of 1.0 per cent is on a correction of 25 per cent to the measured change of length, so that the maximum possible error in the final result that can be ascribed to warping is .25 per cent. Even this small possibility of error is much reduced by the procedure adopted for reducing the final observations, as will be explained below. This check gives confidence in the soundness of the calculation of the correction for change of inclination of the lower probe rod. Under the conditions of the pressure measurement, this correction is much less than above, where the pressure was external only and the conditions as unfavorable as possible, for in the actual experiment the radial displacement is much less than above because the internal pressure to a large extent neutralizes the external pressure. A correction of 0.53 per cent was applied to the final compressibility for this effect.

The mounting of slide wire and contacts has already been shown in Figure 1. The wire was of "Nichrome IV," about 0.013 inch in diameter, with a resistance of about 0.13 ohms per centimeter. The total relative motion was about 0.046 cm, corresponding to a change of resistance of 0.0060 ohms. The constants of the electrical circuit were so chosen that this gave about 50 cm displacement of the slider of the potentiometer. This could be read to 0.1 mm, or 1 part in 5000. So high a sensitiveness was greater than could be used because of the irregularity of the readings, which at the best amounted to 10 times as much, and usually was much more.

The slide wire was calibrated by measuring on the potentiometer the change of resistance for known displacements. The displacements were produced by a screw in an arrangement of obvious enough design, and the the amount of displacement was measured with an Ames 0.0001 inch gauge, which itself was calibrated against standard gauge blocks. The potential and current leads were of pure nickel, 0.008 inch in diameter, attached by electric welding by the discharge from a condenser of suitable capacity charged to 110 volts. In the previous work to 12,000 kg/cm² the terminals had been attached by soft soldering, but in this new high pressure range of 30,000 soldered connections had been sometimes observed to crack because of the high differential compression. Such cracks, even if the connection were not absolutely broken, might introduce irregularities because of indefiniteness of the point of effective contact. In fact the results did show a

notable improvement in regularity after changing from soft solder to the weld.

The correction for the change of resistance of the slide wire under pressure over the entire range up to 30,000 was determined by direct measurement on a piece of wire contiguous in the original length to the piece used for the slide. This piece was 6 cm long, and 4 cm between potential terminals. The change of resistance proved to be linear with pressure over the entire range, with

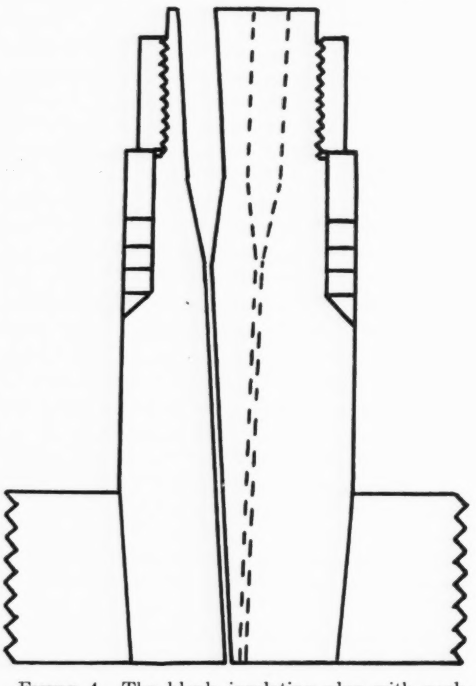

FIGURE 4. The blank insulating plug with packing rings.

a maximum deviation of any single observed point from a straight line of about 1 per cent of the maximum effect. The coefficients were: at 30° $\frac{1}{p}\frac{\Delta R}{R(0,30°)} = -6.55\times 10^{-7}$, and at 75° $\frac{1}{p}\frac{\Delta R}{R(0,75°)} = -6.62 \times 10^{-7}$. The correction to the measured change of resistance arising from the change of resistance of the slide wire with pressure is 12 per cent, so that any error in the final result arising from uncertainty in this correction should be well below 0.1 per cent.

The compressibility of the slide wire also enters as a correction into the final result. The various dimensions are such that the correction on the final result arising from this term is about 5 per cent of the *difference* of compression between nichrome and iron. Previous measurements, not published, up to 12,000 had shown that this difference is one per cent of the compression of iron it-

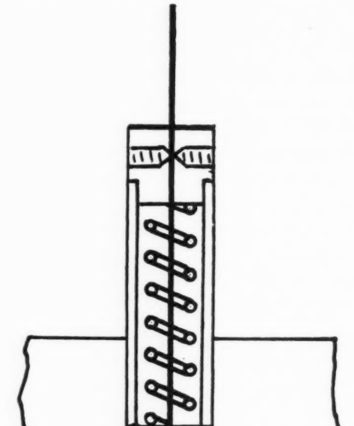

FIGURE 5. Detail of the insulating leads used in the plug of Figure 4.

self. This was taken as sufficient justification for entirely neglecting this correction in the present work without further examination.

In Figure 2 is shown the iron bar, I, mounted in the pressure vessel ready for measurement. It will be noted that three springs are used to keep the various surfaces in contact. Spring A (see

detail in Figure 1) has to be materially stiffer than B, because B pushes against it. These two springs were wound out of piano wire of suitable diameter. At first the spring at C (Figure 2) was not employed, but the iron rod was held in contact with the shoulder on the pressure vessel by a solid nut screwed tightly home. However, various irregularities seemed to have their origin in differential distortion of the rod and the pressure vessel at this point. These irregularities were removed by putting a very stiff helical spring, milled from a solid piece of tool steel, between the nut on the rod and the shoulder on the pressure vessel.

During these compressibility measurements a much more satisfactory solution of the problem of electrically insulating the leads to stand these high pressures was arrived at than had been previously found. This had always been the limiting factor, since it takes much time to set up these insulating plugs and they used to fail either mechanically or electrically after one or two applications of the maximum pressure. Insulation is now provided by a cone of pipestone, A, only 0.005 inch thick, with an angle of about 15° (see Figure 5). The thickness is so small that the pipestone is prevented from shearing out by friction. The shearing stress in the pipestone diminishes exponentially along the length, so that at the apex of the cone, where the wire emerges, the stress is reduced to zero. There is therefore no tendency to blow out the fine piano wire lead, a great advantage over previous arrangements. This arrangement of the pipestone remains mechanically and electrically perfect for a number of applications of pressure. The angle is such that there is no disadvantageous sticking, and the cone can be removed and replaced without renewing the pipestone. The cone carrying the fine stem is of *mild* steel. The piano wire stem is knotted once to prevent pulling through. This scheme of knotting the lead wire was used at the Geophysical Laboratory a number of years ago, with fine copper wire, for a considerably lower pressure range. It would not be possible to knot a piano wire of much larger diameter than that used here, 0.013 inch. The knot on the wire in most of this work was buried in soft solder; this prevents it from cutting itself and also permits a longitudinal pull up to the breaking strength of the straight wire to be applied without cutting through at the knot. However, because of the relatively high differential compression at these high pressures, the solder has a tendency to pull away from the steel, permitting leak past the stem after a number of applications. Toward the end of this work the wire was silver soldered into the cone with better results. In the previous design leak was prevented by the principle of the unsupported area, the pressure in the soft packing being greater than that in the liquid. Now, however, the expelling thrust on the wire is done away with by the action of the cone, and leak has to be prevented by the natural resilience of the soft packing with no help from any differential stress. Fortunately the compressibility of rubber and "Duprene" is low enough so that if the washers are initially cut as large as is possible to crowd into the hole without folding there is still some excess natural diameter left at 30,000 to prevent leak. Special measurements of the compression of an equivalent grade of soft rubber gave a volume decrement of 27 per cent at 30,000 kg/cm^2, from which an idea can be obtained of the initial dimensions in the washer necessary to reach the maximum pressure without leak. However, when the washers are cut as large as they have to be to reach these high pressures, they are almost certain to fold and slip out of the hole unless some guidance is provided. This is done by the helical steel spring pressing down from above, as shown in Figure 5, the top part of the spring pushing against a stop clamped by a screw to the lead wire. Soft rubber and Duprene washers are used, the Duprene being on the side next the liquid to prevent the iso-pentane attacking the rubber, and the rubber doing perhaps the bulk of the packing because of its greater pliability. It is well to renew these washers after several applications of pressure, because they are likely to receive a set, which may lead to leak. Another improvement in the plug is the insulation around the fine stems where they come out through the plug. This was formerly of fine glass tubing, which was constantly breaking under the slight movements of the stems, and short circuiting. The glass is now replaced by silk; half a dozen turns of silk thread are wound around the wire at the mouth of the hole and these are then crowded to the bottom with a tube. The process is continued until the entire annular space, B, between stem and plug is filled with silk. No trouble has been experienced from short circuit in this location since this arrangement was adopted. One has to be sure that the silk initially is quite dry, and in assembling one has to avoid handling it with moist fingers.

It is of extreme importance that all particles of dirt should be eliminated on assembling the

apparatus. As already mentioned, the maximum relative displacement is about 0.047 cm and the maximum deviation from linearity is about 0.0005 cm, so that an exceedingly small particle of grit between the bearing surfaces at any of the three crucial places may have a very large effect. The geometrical arrangement of the bearing surfaces was made as unfavorable as possible to the lodging of grit upon them, and all parts were cleaned before assembly by copious flushing with xylene and blowing out with an air blast.

Measurements, Calculations, and Results

More than twenty-five different set-ups were made and measurements made to 30,000 kg/cm^2 at room temperature. In spite of every effort it was not possible to get rid of capricious irregularities. There probably was no one cause of these, but many of the necessary conditions of the experiment were favorable to such irregularities. Friction cannot be expected to be exactly reproducible, and the steel vessel, continually strained as it is beyond the elastic limit, would be expected to show irregular hysteresis and creep. There seemed nothing to do except to attempt to eliminate the effect of such capricious irregularities by a large number of observations.

In marshalling the measurements a procedure was adopted calculated to eliminate any systematic error due to one effect hitherto not adequately discussed, namely warping of the cross section as a result of which the apparent change of length of the vessel measured at the probe holes is different from that at the interior where the rod is situated. It is evidently only differential warping at the two ends of the rod that is harmful. Warping may arise from various departures of the conditions from those in an infinitely long cylinder with internal pressure along the entire axis. One such effect arises at the two ends, where the internal pressure ceases at the upper and the lower plugs. This effect, however, is probably negligible because the plugs are several diameters removed from the critical region. It would seem that by far the most effective source of warping is tangential drag along the axis arising from friction at the outer and inner surfaces of the vessel. At the outer surface there is such a frictional force when the vessel is forced into its supporting cone, and at the interior there is such a force due to the friction of the moving plug with which pressure is generated. These effects, being different at the two ends, will produce just that differential warping that is especially to be avoided. This warping reverses sign when the direction of friction changes, and therefore reverses when the direction of motion of the moving plug or of the vessel into its cone reverses. The existence of the effect may be demonstrated experimentally by just reversing the direction of motion of the moving plug or of the vessel into its cone at approximately constant values of internal and external pressure. The maximum magnitude of this warping effect amounts to about 1 per cent of the total effect at the maximum pressure. During increasing pressure the effect will be in one direction and during decreasing pressure in the other. It should be eliminated by taking the mean of runs with increasing and decreasing pressure.

These considerations controlled the manipulation of the results. Readings were made at 13 approximately equally spaced pressure points, that is, at 0, 2,500, 5,000, 7,500, etc., both with increasing and decreasing pressure. The change of length of the iron rod was then calculated for each of these measurements, making all the corrections. These results for all the runs were then plotted, in one diagram for the measurements with increasing pressure and in another for those with decreasing pressure. The more discordant of the points at each of the 13 mean pressures were discarded; in a few cases as many as one third of the points were thus discarded, but usually about half as many. The remaining points were averaged, giving 13 approximately equi-spaced points for increasing pressure and 13 for decreasing pressure. A straight line was then passed by calculation through the initial and final points of each of these two groups, and the deviation from linearity, Δ, of the intermediate points calculated. A second degree curve in the pressure of the form $\Delta = a + bp + cp^2$ was then passed by least squares calculation through these deviation points, weighting each point according to the component number of observations which had been retained in the average. In this least squares calculation all 13 points with increasing pressure were retained, but the two highest points with decreasing pressure were not used, for the reason that friction had not entirely reversed itself at these points so that the warping could not be expected to have assumed the value characteristic of decreasing pressure. The total number of component observations used with increasing pressure was 154, and 172 with decreasing pressure. The "standard error of estimate" $\sqrt{\Sigma d_i^2/n}$ of the points with increasing pressure was 0.36 per cent of the total

change of length at the maximum pressure, and of the decreasing points 0.26 per cent. The average of the least squares deviation curves for increasing and decreasing pressure was then combined with the expression from which the deviations had been calculated, to give the final result. The deviation from the straight line of the midpoint of the curve joining initial and final points was 0.92 per cent of the maximum.

The linear term in the final result that would have been calculated from the increasing points differed by only 1.2 per cent from that which would have been calculated from the decreasing points only. The second degree term, on the other hand, from the decreasing points only was 3.6 times greater than that from the increasing points only. The effect of warping is thus much greater on the second degree term, as would be expected.

The final result for the change of length at a mean temperature of 24° is:

$$-\Delta l/l_o = 1.942 \times 10^{-7}p - 0.23 \times 10^{-12}p^2,$$

and for the change of volume:

$$-\Delta V/V_o = 5.826 \times 10^{-7}p - 0.80 \times 10^{-12}p^2.$$

Using only the three smoothest of the many runs and simple graphical methods of calculation, a linear term of 1.939 was found against 1.942, and for the second degree term 0.34 against 0.23. Or if all the measured points had been retained, making no discards, it was apparent without making the calculations that the result would not have been much different; the average compression to 30,000 would have been 0.3 per cent greater.

The result found now is to be compared with my former value[3] up to 12,000 at 24°, namely:

$$-\Delta l/l_o = 1.953 \times 10^{-7}p - 0.75 \times 10^{-12}p^2$$

The linear terms do not differ greatly, but the second degree term now appears to have been formerly much too large. This is the direction in which the theoretical physicists have been insisting was probable. It is also in the direction demanded by the measurements of Ebert[4] on an iron single crystal in the pressure range up to 5,000 kg/cm^2; his second degree term is -0.4×10^{-12}. Exact comparison of my former and present results is hardly possible, because of the difference of range and because there can be only a heuristic significance in the second degree expression used to represent the results. It would be hopelessly beyond the accuracy of either former or present measurements to search for any real departure from the second degree relation.

The most natural point to seize on in attempting to explain the difference between the second degree term found now and formerly is that now the second degree term in the manganin gauge is taken into consideration, whereas formerly a linear relation was used. The deviation from linearity found for the present manganin gauge is in the abnormal direction, the resistance increasing with pressure at a decreasing rate at the higher pressures. The result is that a linear extrapolation from the low pressure readings gives too low a pressure at the high pressures. Hence as far as the present gauge is concerned the linear compression of iron would have been found more linear than it is if a linear calibration had been used for the manganin. However the effect is small: at 30,000 the true pressure is 1.3 per cent greater than would have been obtained from a linear extrapolation of the manganin gauge from 15,000. Using a linear relation for the manganin would have given a second degree term in the compression of iron only one third that given above, which is in the wrong direction to explain the discrepancy. The situation, however, is by no means simple, and it is not possible to argue back with certainty from these results to the previous source of difference. The second degree term in the manganin has to be found by individual calibration of each coil, and differs appreciably for contiguous pieces from the same spool. The manganin used in the previous work was from an entirely different source from the present manganin. If the former manganin had a small second degree term of the normal sign the former larger value of the second degree term in the compression of iron would be accounted for. The possibility cannot be ruled out that the curvature of the relation between the resistance of manganin and pressure reverses on passing from a low pressure range to one more extensive. It must furthermore be remembered that because of the difference of range the accuracy of the second degree terms in the present work is, other things being equal, more than six times that of the previous work.

It was my original hope to also measure the temperature coefficient of compression with this apparatus. In view, however, of the difficulties encountered in the measurements under the comparatively favorable conditions at room temperature it seemed hardly practical to try for the temperature effect. The best that can be done at present is to use the former value for the temperature coefficient. This would give at 75°:

$$-\Delta l/l_o = 1.964 \times 10^{-7}p - 0.23 \times 10^{-12}p^2.$$

ACKNOWLEDGEMENTS

I am much indebted to the skill of my mechanician, Mr. Charles Chase, in the difficult and tedious task of setting up the apparatus. For financial assistance I am indebted to the Rumford Fund of the American Academy of Arts and Sciences and to the Francis Barrett Daniels fund of Harvard University.

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